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REVIEW ARTICLE

The benefits and applications of consortium systems for sustainable agriculture

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Abstract

Agricultural consortium systems emerge as a promising strategy to tackle the challenges of modern agriculture. This comprehensive review analyzes the main consortium systems. Therefore, the aim of this research is to provide a detailed understanding of intercropping systems, their practical applications, and their potential to contribute to more sustainable agriculture. The methodology involved a systematic review of recent scientific articles dealing with the six main intercropping systems recurrent in the literature: grains and legumes, agroforestry, cover crops, crop-livestock integration, perennial annuals, and vegetables, including meta-analysis, with qualitative and quantitative analyses adopted to understand the benefits that intercropped systems reflect on soil quality, as well as in promoting innovation in sustainable management. The results, visualized through Sankey diagrams and boxplots, reveal that these systems can increase productivity, significantly improve soil health, promote biodiversity, improve resource use efficiency, and strengthen climate resilience. Notably, the intercropping of grains and legumes and agroforestry systems demonstrated the most comprehensive benefits. Cover crops had a particularly strong impact on soil health, while agroforestry systems stood out in terms biodiversity and climate resilience. The study also suggests a potential reduction in the use of chemical inputs. We conclude that the broader adoption of intercropping system is an effective strategy for more sustainable and climate resilient agriculture, although challenges to large-scale implementation remain.

Keywords

Agricultural security, biodiversity, climate resilience, consociation, soil health

Introduction

Crops in intercropping systems highlight the innovative vision to address the complexities imposed by contemporary agriculture, encompassing the need to expand food production, enhance sustainability, and preserve environmental benefits. These systems are defined in a simultaneous cultivation or interspersing various plant species in the same area, with the purpose of taking advantage of the beneficial interactions between species in the pursuit of improvements in resource utilization with the aim of increasing overall productivity (Li et al. 2001; Tamburini et al. 2020).

Intensive food production systems, such as monoculture, harm the environment, primarily through the excessive use of agrochemicals and fertilizers, which still need to prove their ability to eradicate hunger in developing countries, as this group of agricultural practices with various limitations still results in low nutritional quality of products intended for human and animal consumption, which can be related to health problems (Singh et al. 2022). Thus, the increasing concern from society regarding global food security, associated with the effects of climate change and the use of environmental resources, has sparked interest in more sustainable and resilient agricultural practices (Yu et al. 2022; Maitra et al. 2021).

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Recent research highlights the growing importance of sustainable agricultural practices in addressing climate change. A 2024 study on the regenerative agriculture market in Spain projects significant growth, with the market expected to reach $948.69 million by 2029, growing at a CAGR of 14.88% since 2023 (Research and Markets 2024). This trend is driven by a commitment to restoring soil health and mitigating climate change, demonstrating the growing recognition of sustainable agricultural methods as relevant tools in addressing global environmental challenges, while ensuring food security. Thus, current research has ensured that intercropping systems have the potential to significantly reduce the demand for chemical inputs, considering that the excessive use of agrochemicals and fertilizers considerably harms the environment (Duchene et al. 2017; Rosa-Schleich et al. 2019).

However, a variety of consortium systems have been developed in different agricultural contexts, including the main types of consortia such as grains and legumes, crop-livestock, and agroforestry. Each of these systems, in turn, presents various benefits and challenges, contributing in different ways, in particular, to sustainable agricultural crops and resilience ecosystems (Glaze-Corcoran et al. 2020; Khanal et al. 2021). Recent comparative studies show that the choice of the most suitable intercropping system can vary significantly depending on climatic conditions and soil type (Brooker et al. 2015; Stomph et al. 2020).

Therefore, to exemplify the effectiveness of intercropping systems in terms of agricultural productivity, studies have shown that grain crops, such as corn intercropped with legumes, can significantly increase crop yields compared to monocultures, improving nutrient use efficiency, especially nitrogen (Dai et al. 2019; Chamkhi et al. 2022).

These systems present a variety of specific advantages and challenges and can contribute differently to the sustainability of agriculture and the conservation of the environment (Glaze-Corcoran et al. 2020; Khanal et al. 2021). Comparative research demonstrates that this aspect can be significantly dependent on climate and soil constituent type (Brooker et al. 2015; Stomph et al. 2020).

The effectiveness of intercropping systems in optimizing agricultural productivity has been widely documented. An example of this is studies proving that the combination of some crops with legumes can significantly increase crop yields compared to monocultures, succeeding with proper management to make nutrients available in the soil solution (Dai et al. 2019; Chamkhi et al. 2022). As well as some intercropping methods having the ability to reduce greenhouse gas emissions when compared to monocultures (Senbayram et al. 2015; Vanlauwe et al. 2019).

The productivity of crops is interrelated with the quality of soil characteristics, as these intercropping systems can have a beneficial impact. For example, cover crops are related to changes in soil structure, an increase in organic matter content, and a positive effect on soil biological activity (Nyawade et al. 2019; Roohi et al. 2022; Akchaya et al. 2025). More recently, research has demonstrated these advantages by showing increases of 30% in soil organic matter content over five years and increases of 40% in over five years in the water retention capacity in intercropping systems cultivated with cover crops (Blanco-Canqui et al. 2015; Finney et al. 2017).

The promotion of biodiversity constitutes an essential benefit of intercropping systems. Agroforestry systems and vegetable intercropping, in particular, have been correlated with considerable increases in species diversity, both above ground and in the soil, favoring the stability and resilience of agricultural ecosystems (He et al. 2019; Huss et al. 2022). Updated results from some studies have expanded this understanding, showing that modified intercropping systems can increase pollinator diversity by up to 50% and the number of natural enemies by up to 60% (Iverson et al. 2014; Lichtenberg et al. 2017).

The extensive use of resources constitutes an essential quality of consortium systems. Through complementarity and facilitation in the interaction between different species, such systems are capable of maximizing the use of water, nutrients, and sunlight, preventing dependence on external inputs and mitigating adverse environmental effects (Renwick et al. 2020; Zhang et al. 2021). Many studies have measured these advances, showing that properly updated intercropping systems can increase water use efficiency by up to 25%, as well as nutrient use efficiency by up to 35%, compared to monocultures (Mao et al. 2012; Hauggaard-Nielsen et al. 2016).

In the current scenario of climate change, the resilience of agricultural systems is becoming increasingly important. Intercropping systems, especially those that incorporate perennial crops, have shown greater resilience to extreme weather events and better adaptation to changes in environmental conditions (Clermont-Dauphin et al. 2018; Gardner et al. 2023).

The aim of this review is therefore to provide a detailed understanding the three main types of agricultural cultivation systems, their practical applications, and their potential to contribute to more sustainable agriculture.

Methodology

The present study was carried out by means of a thematic literature review, based on the premise that qualitative research, when studying crops in a consortium system aimed at maintaining soil quality and used as sustainable management, is capable of achieving the established objective. The method used was to search for and collect information on the topic under study, in order to synthesize and present the information produced on the research topic.

The review was based on 55 articles with robust methodologies, including experimental studies, meta-analyses, and systematic reviews that were consulted from different sources (MDPI, Scopus, Web of Science, Google Scholar, and SciELO). The search terms included the following keywords: consortium, sustainable agriculture, crop diversity, resource use efficiency, productivity improvement, soil health, biodiversity, climate resilience, agroecology,

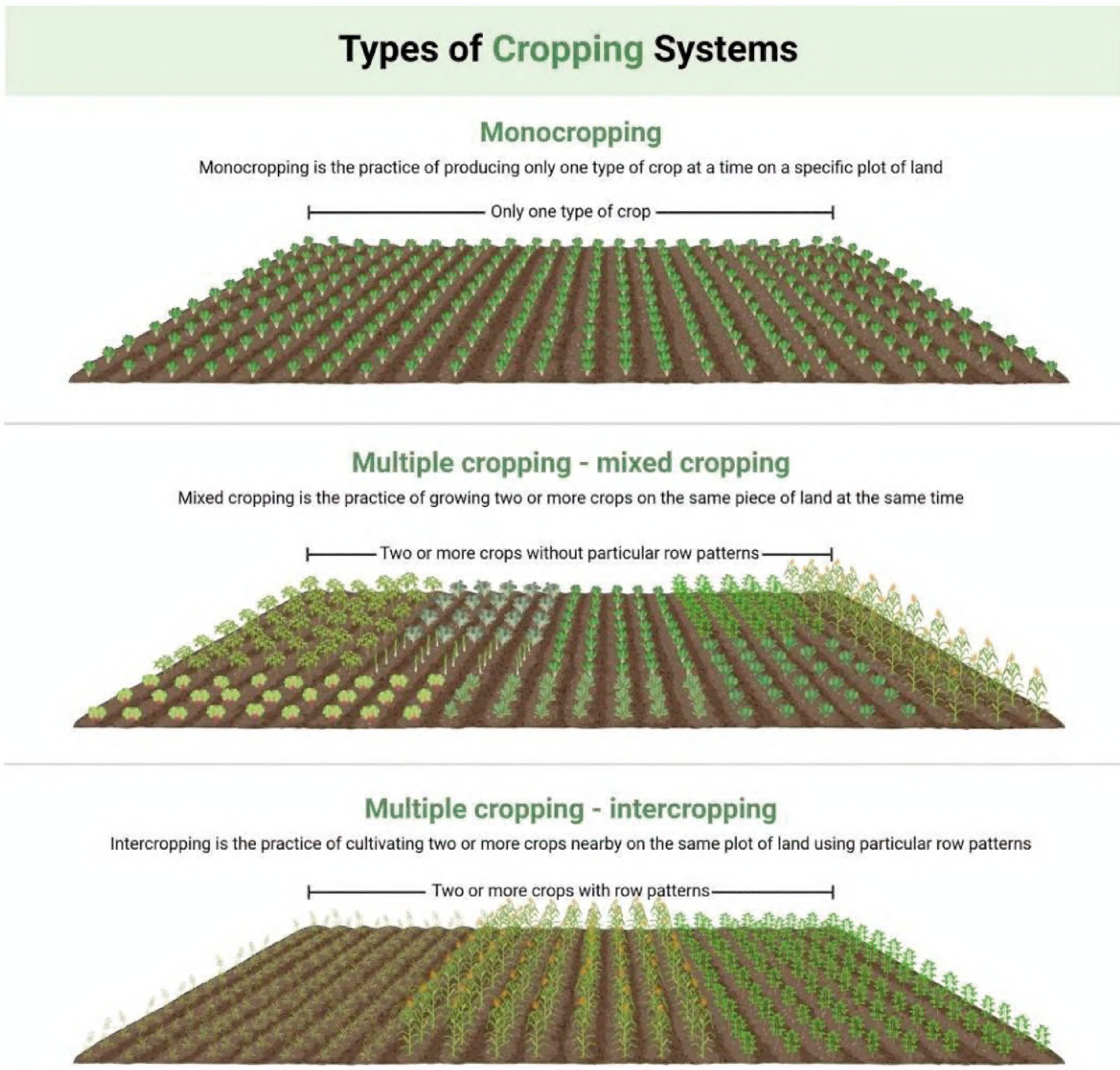
Types of Cropping Systems
Monocropping
Monocropping is the practice of producing only one type of crop at a time on a specific plot of land
Only one type of crop
Multiple cropping - mixed cropping
Mixed cropping is the practice of growing two or more crops on the same piece of land at the same time
Two or more crops without particular row patterns
Multiple cropping - intercropping
Intercropping is the practice of cultivating two or more crops nearby on the same plot of land using particular row patterns
Two or more crops with row patterns

Figure 1. Visual comparison of the three main types of agricultural cultivation systems: (**a**) *Monoculture*: Cultivation of a single plant species in a specific area; (**b**) *Multiple cropping – mixed cropping*: Simultaneous growth of two or more crops in the same area without a specific row pattern; (**c**) *Multiple cropping – intercropping*: Cultivation of two or more crops in the same area using specific row patterns. This figure illustrates the differences in the arrangement and diversity of crops between monoculture, mixed cropping, and intercropping systems, highlighting the unique characteristics of each agricultural approach (Bio Render 2025).

and ecosystem services, along with their respective translations into English.

The compilation of data from the selected articles was supported by the systematic literature review we conducted on agricultural consortium systems. The criteria adopted for this compilation were articles that addressed the six main intercropping systems recurring in the literature: grains and legumes, agroforestry, cover crops, crop-livestock integration, perennial annuals, and vegetables. Categorized according to the main benefits analyzed (for example, productivity, soil health, biodiversity, resource use efficiency), allowing for a more focused analysis of each consortium systems aspect. For each analysis, was evaluated the reported benefit intensity for each consortium system on a scale of 0 to 10, where 0 indicates no significant benefit and 10 indicates a very strong benefit. We converted qualitative descriptions into numerical values when necessary (e.g., "high benefit" = 8–10, "moderate benefit" = 5–7, "low benefit" = 1–4).

In meta-analysis context, we compiled the data from all the studies, calculating averages and variations for each combination of intercropping system and benefit. In this way, in each study, we extracted quantitative data on five main benefits of intercropping systems: Nitrogen fixation (N_Fixation), Increase in soil organic matter (Soil_OM_Increase), reduction of greenhouse gases

(GHG_Reduction), water efficiency (Water_Efficiency), and increase in yield (Yield_Increase). When the studies reported ranges or multiple values, we calculated the average value for our analysis. For all data analyses and visualizations, R Software (version 4.4.1) was used (R Core Team 2024). The following R packages were used: tidyverse (Wickham et al. 2019) for data manipulation, ggplot2 (Wickham 2016) for creation of visualizations and networkD3 (Allaire et al. 2017) for generating the Sankey diagram.

According to the methodology that was implemented, for the benefits quantitative analysis of consortium systems, two data visualization methods were used, the Sankey diagram (Fig. 2) and Box Plot (Fig. 3). These were developed based on a data meticulous analysis extracted from the selected articles. Thus, the frequency and intensity of the reported relationships between systems and benefits were used to determine the flows thickness (Fig. 2). Thus, a matrix of connection strengths between intercropping systems and benefits was created. The strength of each connection was calculated as:

Strength of the connection = (Frequency of the reported benefit / Total studies) * (Average value of the reported benefit / Maximum value of the reported benefit)

On the other hand, the data were also organized in a long format, with columns for Systems, Benefit, and Value (Fig. 3), since for each combination of intercropping system and benefit, we calculated the following statistics: Median: calculated using the median function in R; Interquartile range (IQR): calculated as Q3 - Q1, where Q1 and Q3 are the first and third quartiles, respectively; Outliers: identified using the 1.5 * IQR rule. Any data point below Q1 - 1.5 * IQR or above Q3 + 1.5 * IQR was considered an outlier.

A quantitative analysis was also conducted (Fig. 4) on the cereal-legume intercropping system benefits, where these data were generated to represent four intercropping systems: corn-soybean, wheat-fava bean, barley-pea, and sorghum-bean. For each cereal-legume intercropping systems, five observations were made, covering five performance metrics: nitrogen biological fixation (45–150 kg N/ha/year), increase in soil organic matter (5–15%), reduction of greenhouse gases (13–30%), water use efficiency (13–24%), and increase in productivity (12–29%). The variability within each system was introduced to assess real field conditions, considering factors such as climate, soil, and management practices.

In addition, more recent analyses report increases in productivity (up to 35%), water use efficiency (20–25%), nutrient retention (25–30%), and reductions in pest damage (20–25%) (Akchaya et al. 2025). The integration of cereals and legumes has also been associated with reductions in greenhouse gas emissions (10–35%), soil conservation, and improvements in soil organic fertility (Prajapati et al. 2025).

The studies that did not meet these conditions were not considered for development in this part of the work. However, some are mentioned in other sections because they contain critical points regarding the proper development of intercropping systems that aim to improve food security.

Results and discussion

Consortium of grains and legumes

The consortium of grains and legumes stands out in this aspect (Fig. 3), presenting a high median and a distribution concentrated in the upper portion. This fact is in accordance with current research that shows substantial increases in total productivity when cereals and legumes are cultivated together, especially due to the nitrogen fixation carried out by the legumes.

This system shows strong connections with the enhancement of productivity, the efficiency in the use of available resources, and the attributes of the soil. The interaction between cereals and legumes impresses with various advantages, such as the ability of legumes to fix nitrogen present in the atmosphere, which benefits grain crops, resulting in significant increases in production factors. However, the intercropping of wheat with corn or wheat with soybeans, in strips, not only increased productivity but also improved nutrient use efficiency. Thus, such success becomes essential to reduce the dependence on artificial fertilizers, thereby promoting the sustainability of agricultural systems (Li et al. 2001).

The information regarding the increase in productivity (Fig. 4) shows significant variability between the systems, with corn-soybean and wheat-fava presenting higher medians and wide interquartile ranges. The most significant productivity increases found in the systems containing maize-soybean and wheat-fava were correlated with the growth patterns of the complementary plants and the efficient use of resources by these crops (Li et al. 2020). A moderate growth of soil organic matter was observed in all systems, and the corn-soybean system showed a median and an upper quartile. This observation is in line with a study by long duration, finding that the continuous rotation between corn and legumes provided sustainable increases in soil organic carbon. The relatively reduced interquartile ranges regarding the increase in soil organic matter in all systems indicate a consistent, albeit moderate, benefit in this aspect of soil health (Takriti et al. 2018).

At the same time, a series of studies have shown that intercropping systems not only increase productivity but can also improve the nutritional quality of crops. According to one of the studies, the productivity and additional protein content of corn grains increase with the combination of corn and soybeans. The improvement of nutritional quality through the synergistic effect of corn and soybeans in such strategic products is of particular importance in the context of food security (Xue et al. 2016).

When examining the ecological foundations that support the increase in productivity in intercropped cereal and legume cultures, especially in organic farming systems,

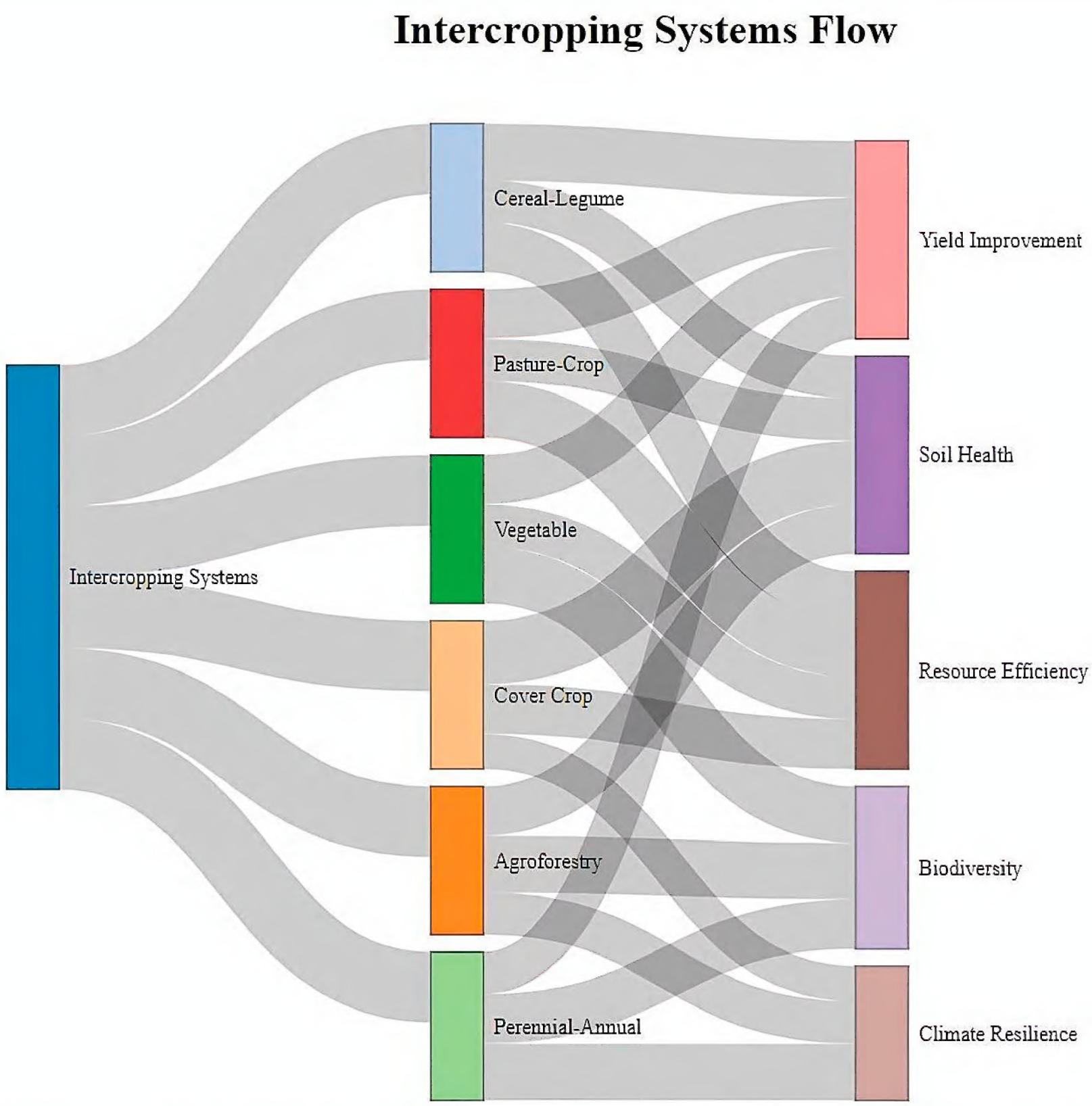

Figure 2. Benefit Flow in Agricultural Consortium Systems. The Sankey diagram illustrates the relationships between six consortium systems (on the left) and five categories of benefits (on the right). The thickness of the connections represents the intensity of the benefit observed in each system, based on the analysis of recent published studies (Authors 2025).

the interactions between different species are planned to optimize resource use efficiency, with an emphasis on nitrogen. This increase (Fig. 2) stands out for the robust connection between cereal and legume systems and the efficiency in resource utilization (Bedoussac et al. 2015).

The relationship with soil health, although not as intense as observed in cover crops, remains relevant, as intercropping increases carbon and nitrogen levels in the soil, promoting long-term fertility and improving soil structure (Cong et al. 2015).

It has therefore become evident that concentration fixation represents a significant benefit in legumes (Fig. 4), with the molecules of corn, soy, and fava bean showing particularly high median values, in addition to expanded interquartile ranges. Such a statement converges with the conclusions of several studies in our analysis. Consequently, another study indicated that legumes in intercropping systems are capable of fixing between 100 and 300 kg/ha of nitrogen per year, which is reflected in the high values and variability observed in the same figure (Peoples et al. (2009). The high efficiency of the corn-soybean and wheat-fava system in Nitrogen fixation demonstrated that the association of peas with barley reduced the need for nitrogen fertilizers by up to 40% (Hauggaard-Nielsen et al. 2009).

The variability, particularly regarding nitrogen fixation and productivity increase (Fig. 4), emphasizes the relevance of considering local conditions and management strategies when implementing the selection of a more protected intercropping system, which may differ and benefit depending on climatic conditions and soil type (Brooker et al. 2016; Stomph et al. 2020).

When conducting a comparative analysis between the systems, it is observed that corn-soybean and wheat-fava consistently present higher medians and expanded interquartile ranges for most advantages, especially regarding nitrogen fixation and increased productivity. Thus, such systems can provide more significant and diversified advantages compared to other intercropping systems.

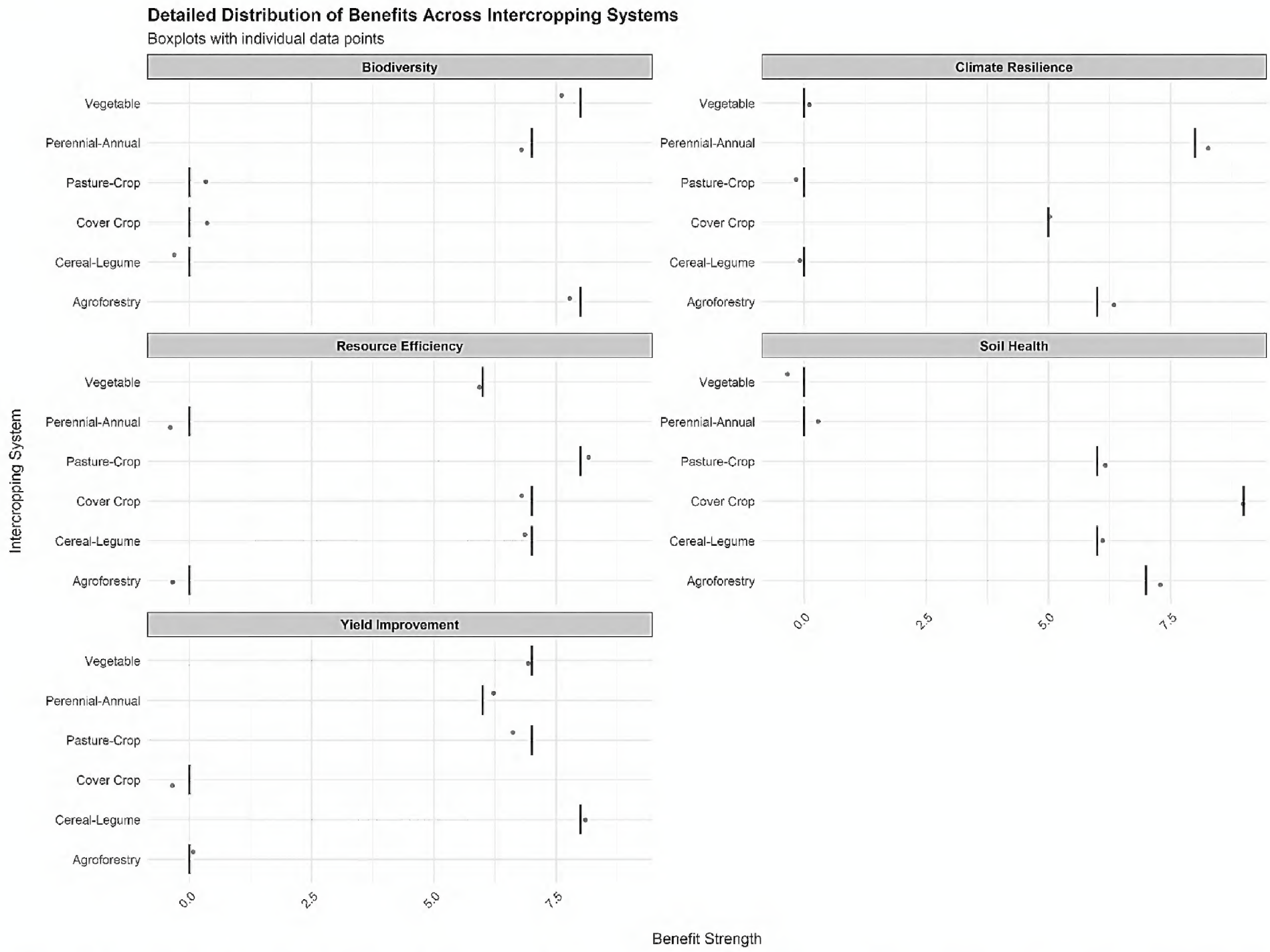

Figure 3. Distribution of Benefits by Agricultural Consortium System. The boxplot graph presents the variability of the benefits observed in each consortium system. The boxes show the interquartile range, with the central line representing the median. The whiskers indicate the minimum and maximum values, excluding outliers. This visualization allows for a detailed comparison of the effectiveness of each system in relation to the five main benefits identified in the literature (Authors 2025).

However, it becomes evident that all intercropping systems show positive effects in all evaluated parameters, validating the importance of intercropping grains and legumes in sustainable agriculture.

Although the results (Figs 2, 3) show substantial advantages for soil health, it is important to highlight the long-term impacts of the systems, whereby the continuous practice of intercropping corn and legumes provided a lasting increase in soil organic carbon and microbial activity, presenting beneficial effects that persisted even after the resumption of monoculture. This indicates that the advantages of intercropping systems for soil health may persist beyond the period of their implementation (Cong et al. 2018).

The benefits resulting from the reduction of Greenhouse Gases are generally consistent across all intercropping systems involving grains and legumes (Fig. 4), with the corn-soy system standing out for showing a median slightly above 20% in the emissions of these gases in associations with the cereal and legume system, compared to monocultures of grain crops. The consistency in GHG reduction across all systems emphasizes the capacity of this type of consortium as a solution for mitigating greenhouse gas emissions (Senbayram et al. 2015).

Another aspect that deserves attention is the potential of consortia systems for carbon sequestration. Some studies have revealed a significant increase in soil carbon stocks from maize cultivation in consortium with legumes, in contrast to monoculture maize. In this way, this benefit contributes to the efficient maintenance of soil fertility and quality in the long term (Cong et al. 2015).

Simultaneously, another significant factor that deserves attention is the improvements in water efficiency, as the data showed a uniformity among the different intercropping systems, with the fava bean and wheat system presenting a higher median (Fig. 4). This fact is in line with the demonstrations presented in related research, which indicate that properly designed intercropping systems can increase water consumption efficiency by up to 25%. The uniformity in improvements regarding water efficiency among the systems indicates that such an advantage constitutes a solid characteristic of intercropping grains and legumes, regardless of the specific combination of crops (Mao et al. 2012; Hauggaard-Nielsen et al. 2016).

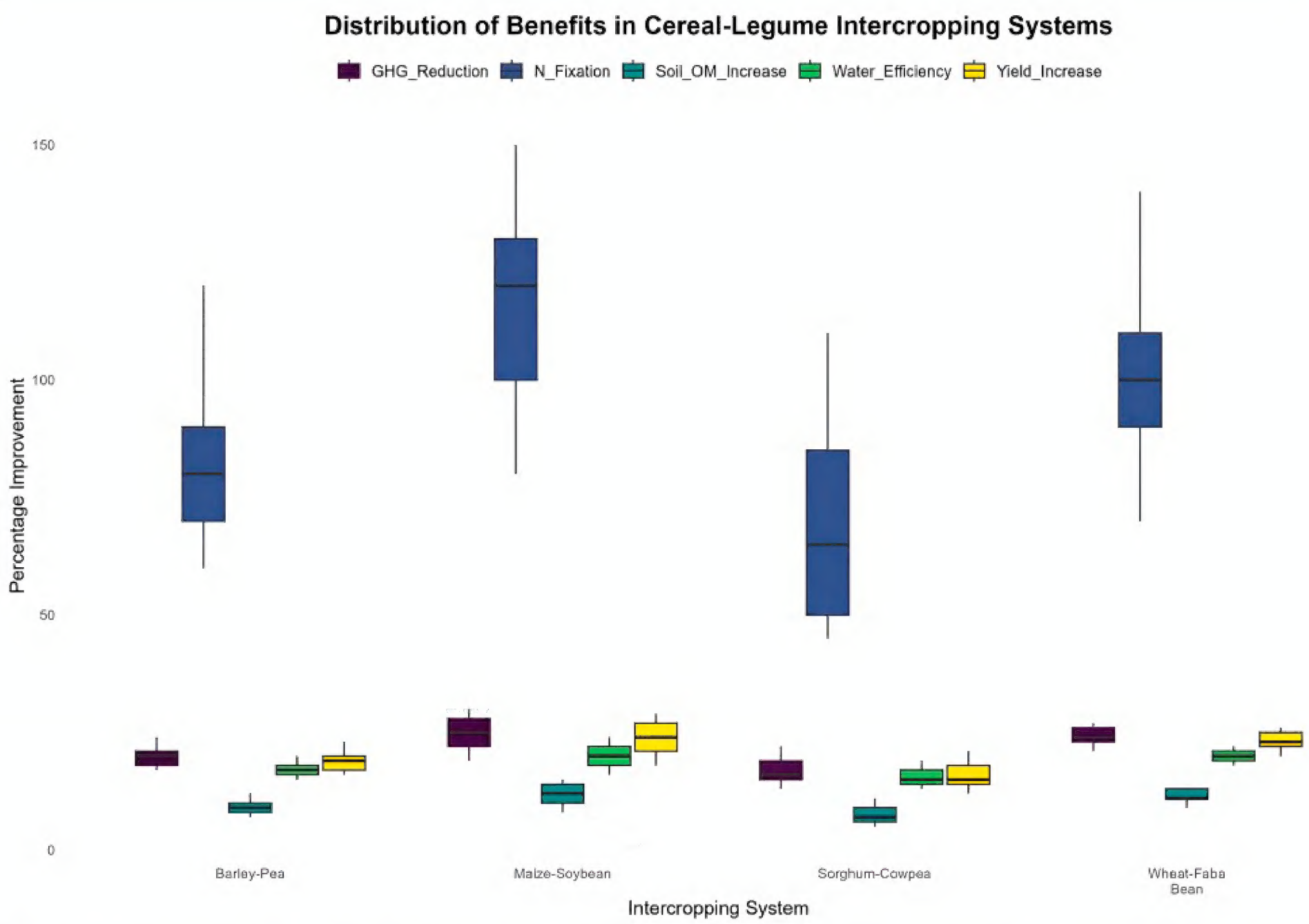

Figure 4. Distribution of benefits in legume-cereal intercropping systems. This box plot illustrates the percentage of improvement in five key metrics (GHG Reduction, N Fixation, Soil Organic Matter Increase, Water Efficiency, and Yield Increase) in four different cereal-legume intercropping systems (Barley-Pea, Corn-Soybean, Sorghum-Bean, and Wheat-Fava). The chart demonstrates the variability and median values of each benefit for each cereal-legume intercropping system, allowing for a comparative analysis of their performance.

Agroforestry systems

Agroforestry systems and vegetable intercropping stand out with the highest benefits for biodiversity, with high median scores and technical distributions at the top (Fig. 3). Both systems show the ease of ensuring the greatest dispersion of scores to establish more varied habitats and generate a wider range of species not only on the surface but also underground.

The study also depicted the more equitable allocation of advantages of agroforestry systems with significant connections to biodiversity, soil quality, and resilience to climate change (Fig. 2). This confirms the ecologically natural advantages of agroforestry approaches.

A meta-analysis published that, compared to controls, agroforestry systems increased biodiversity and the entire ecosystem in Europe. The trees present these protected ecosystems for various species (Fig. 2), which vary from soil microorganisms to birds and insects, which highlights the close relationship with biodiversity (Torralba et al. 2016). Based on the above, upon observing that there was an increase in soil organic carbon levels in agroforestry areas in France, a reconditioning of soil structure was noted, resulting from the continuous incorporation of organic matter from litter and root systems, as well as acting under the control of surface soil erosion (Cardinale et al. 2018). Furthermore, trees in agroforestry systems capture carbon, provide shade, and also serve to protect other species from winds, in addition to contributing to mitigating the impacts of severe climatic conditions (Mbow et al. 2014).

Intercropping of cover crops

The cover cropping system exhibits the greatest benefits for soil health, as evidenced by both the median values and the upper bound associated with this management practice (Fig. 3). This finding underscores the critical role of cover crops in enhancing soil structure, increasing organic matter content, and stimulating soil biological activity. Notably, cover cropping systems demonstrate a stronger association with soil attributes and are significantly linked to improved resource-use efficiency and climate adaptation capacity (Fig. 2).

Several meta-analysis and reviews support the benefits of intercropping cereals and legumes. For example, intercropping systems increase the proportion of biologically fixed nitrogen in legumes by about 14% and increase soil

nitrogen uptake by cereals by 61% compared to monocultures; total nitrogen used in the soil is 25% higher in intercropped systems compared to legumes alone (Rodriguez et al. 2020). On a global scale, it is estimated that such systems can reduce the use of synthetic nitrogen fertilizers by approximately 26%, while improving yield stability, productivity per unit area, reducing pest incidence, and promoting biodiversity (Jensen et al. 2020).

However, these crops promote the ecological intensification of cultivation systems by contributing to the increase of organic carbon in the soil, improving its structure, and enhancing nutrient cycling. These advantages explain the strong relationship with soil quality in the graph (Wittwer et al. 2017). These benefits provided by cover crops in temperate soils have improved water quality, carbon capture, and other qualities of the physical characteristics of the soil. However, these findings (Fig. 2) for the improvement of soil quality and the efficient use of water favor the resilience of agricultural systems (Blanco-Canqui et al. 2015).

Vegetable consortium

Vegetable intercropping systems are linked to improved productivity and biodiversity, showing moderate connections with efficiency in resource utilization (Fig. 2). This highlights the intensive nature of various vegetable cultivation systems, as well as the possibilities of complementarity between specific species of these plants.

Intercropping increases productivity and preserves soil fertility characteristics compared to the isolated cultivation of these vegetables (Fig. 2). This elucidates the intense relationship with the improvement of productivity (Wang et al. 2014).

When examining the influence of agricultural diversification on insect communities in cruciferous crop plantations, it is found that intercropping can reduce the pressure exerted by deliberations and enhance the legislation of beneficial insects, thereby promoting both biodiversity and increased productivity (Hooks and Johnson 2003).

Perennial-annual intercalation

Perennial annual systems have the strongest link with climate adaptability, showing significant connections with biodiversity and increased productivity (Fig. 2). Although alley cropping, a system in which perennial crops are interplanted with annual crops, may seem unusual, the potential exerted by this method allows for innovation in agriculture. However, the ability of these systems to optimize certain characteristics in agricultural areas can ensure greater profitability for the producer (Wolz et al. 2018).

When analyzing the potential of perennial grasses in intercropping systems, it was concluded that such systems could offer continuous yields while simultaneously enhancing ecosystem services, elucidating the relationships between increased productivity and biodiversity (Crews et al. 2016).

The Perennial-Annual and Agroforestry systems reveal the greatest benefits in terms of climate resilience, as demonstrated by the high medians and distributions (Fig. 3). This indicates that the inclusion of perennial elements in the agricultural system can constitute an effective strategy to enhance adaptability to climate change. Although it has been indicated that perennial-annual systems have a strong relationship with climate resilience, it is critical that all consortia subsystems have the potential to adjust to climate changes (Fig. 2).

The diversity within consortium systems creates a sense of a "portfolio effect," however, the likelihood of encountering harvest problems is inherently lower due to the variability of specialized responses specific to stress related to climate. Such consideration is especially relevant in the context of extreme climate events that have been occurring frequently in recent years (Lin 2011). Furthermore, certain systems (Fig. 3), such as the Perennial-Annual and the Vegetable systems, exhibit greater variability in certain benefits, evidenced by boxes of larger dimensions. This indicates that the results of these systems may be more influenced by site-specific factors or management practices.

Intercropping pastures with agricultural crops

Pasture-crop systems present harmonious benefits, with deep connections to resource efficiency, yield enhancement, and soil health (Fig. 2). This demonstrates the synergies between crop production and livestock farming in integrated systems.

The combined crop and livestock systems in the Southeastern United States have facilitated advances in both agricultural production and livestock farming, as these systems have improved soil quality and enhanced nutrient cycling, elucidating the interrelationships between soil health and resource efficiency (Franzluebbers and Stuedemann 2014).

To achieve this synergy, many strategies have been developed, through which various crop-livestock systems have the potential to improve the nutrient cycle and reduce dependence on the consumption of external inputs (Fig. 2), reallocating land use in a manner consistent with the representation of benefits and productivity (Peoples et al. 2009).

Furthermore, a visualization of the advantages provided by the various intercropping systems in relation to agricultural sustainability aspects was presented (Fig. 2). It is also possible to highlight the ability to varied agricultural systems when facing major issues in agriculture, encompassing several factors that are part of the soil-plant-environment interaction.

The equitable distribution of advantages among various intercropping systems indicates that a planned agricultural production strategy, which includes multiple approaches to this cultivation method, could offer a more comprehensive solution for sustainable food production. However, the practice of intercropping constitutes a new Green Revolution, providing alternatives for the

sustainable intensification of agriculture, capable of meeting the growing demand for food while preserving ecosystem services (Martin-Guay et al. 2018).

In the present context, robust interconnections between various systems and the effectiveness in resource utilization were evidenced (Fig. 2), with an emphasis on Pasture-Crop and Cereal-Legume systems. Parallely, (Fig. 3) corroborates this trend, highlighting beneficial distributions for these systems.

System integration

The combined evaluation (Figs 2, 3) suggests that different consortium systems can be complementary to each other. An example of this was validated when the grain and legume consortium showed improvements in yield and resource use efficiency, where Agroforestry systems ensure superior benefits in terms of biodiversity and climate resilience.

The present visual analysis of the data corroborates the conception that consortium systems have designed an approach for sustainable agricultural practice. Therefore, it is emphasized that the implementation of variable consortium systems tailored to local specificities can represent an efficient approach to dealing with the complex challenges of contemporary agriculture, encompassing food security, environmental preservation, and adaptation to climate change.

Conclusion

This review demonstrates that the different integrated agricultural consortium systems evaluated offer numerous complementary and competitive advantages and have the potential to provide comprehensive solutions for contemporary sustainable and environmentally responsible agriculture.

Agricultural consortium systems with grains and legumes, cover crops, and agroecosystems provide positive impacts and a greater number of benefits for soil health in terms of optimizing the use of chemical inputs and environmental resources, as well as increasing biodiversity and climate resilience.

Agricultural consortium systems, in addition to the proprietary technologies development, require a broad knowledge base of the intrinsic interactions between crops and the environment and constitute a promising strategy for achieving the goals of food security, environmental preservation, and adaptation to climate change. There is also a need to assess how intercropping systems can be effectively integrated into agricultural policies and rural support programs

Author contributions

Conceptualization: FALD, JVS. Formal analysis: JVS, EOAJ, LSSA. Investigation: JCSC, IBS. Supervision: JVS. Validation: JVS. Visualization: IBS. Writing – original draft: EOAJ. Writing – review and editing: LSSA.

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